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Wave Particle Interactions on Relativistic Electron Beams

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Papers Prepared for Publication

"Free-Electron Laser with a Strong Axial Magnetic Field," L. Friedland and J. L. Hirshfield, Phys. Rev. Lett. June (1980).

"Electron Beam Dynamics in Combined Guide and Pump Magnetic Fields For Free Electron Laser Applications, L. Friedland, submitted to Phys. Fluids (should have acceptance soon).

Personnel: Ira B. Bernstein, Professor of Applied Science
Jay L. Hirshfield, Professor of Applied Science
L. Friedland, Research Associate (no compensation from this contract)

Other Government Sponsored Research with Which Principal Investigators are Associated

Ira B. Bernstein: Topics in Theoretical Plasma Physics
NSF Grant PHY78-08443
July 1, 1978 - June 30, 1980
$29,900 FY 1979

Numerical Solution of the Fokker-Planck Equation
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May 11, 1977 - October 31, 1980
$88,000 FY 1979

Jay L. Hirshfield: Ion Confinement in Laser-Iniated Vacuum Arcs
DOE Contract EG-77-C-02-4363
$310,000 Feb. 16, 1977 - Feb. 15, 1980
$115,000 Feb. 16, 1980 - Feb. 15, 1981

Experiments with Waves on Relativistic Electron Beams
AFOSR Grant 80-0025
$47,018 Oct. 1, 1979 - Sep. 30, 1980

Research on Gyrotrons
ONR Contract N00014-80-C-0075
$314,195 Oct. 1, 1979 - Sep. 30, 1980

SUMMARY OF SCIENTIFIC PROGRESS TO DATE

Summaries are provided on the following topics:

1. Linearized Theory Including Axial Magnetic Field

The linearized theory of the operation of a free electron laser consisting of a relativistic electron beam in a helical pump and axial confining magnetic fields has been formulated. An exact solution has been found for the case of a cold beam. The dispersion relation has been derived, analyzed, and examined numerically. For the case of very high frequency radiation and large beam energy it has been shown that the gain characteristics are not markedly changed from those calculated in the absence of the guide field.[1] At lower frequencies and energies additional regions of gain seem possible. A manuscript has been completed and is being prepared for distribution. Typical gain curves and line shapes are presented. Work is continuing on thermal effects.

2. Non-Linear Theory

The non-linear theory of a steady state free electron laser amplifier consisting of a relativistic electron beam in helical pump and axial confining magnetic fields illuminated by monochromatic radiation has been formulated. The introduction of Lagrangian variables permits an exact integration of the continuity equation to express the current density at a general field point in terms of the current density at injection and the velocity at the field point in question. The axial electric field is found in a similar way by integrating Poisson's equation. The parallel momentum equation is reduced to an ordinary differential equation and permits the electron orbits to turn in the wave frame, corresponding as one advances along the beam in the direction of propagation to the development of multistreaming. The reduced equations, and the coupled wave equations for the transverse vector potential are being analyzed, and suitable numerical methods for their solution are being determined. Preliminary numerical studies are about to begin.

3. Quasi-Linear Theory and Single Particle Theory for Free Electron Laser with a Strong Axial Field

A quasi-linear theory of the steady free electron laser amplifier consisting of a helical pump and relativistic electron beam illuminated by a monochromatic wave has been formulated. A linearized WKB description is employed to describe the electromagnetic field, and the steady state density, mean velocity, etc. are determined correct to second order in the high frequency amplitude. The helical pitch is allowed to vary with position so as to keep the system in a configuration of maximum gain as the beam decelerates on converting its energy into radiation. The analysis of the results is continuing, numberical studies are underway, and a preliminary manuscript is being prepared.

[1] I. B. Bernstein and J. L. Hirshfield, Phys. Rev. A 20, 1661 (1979).

4. Single-Particle Theory for Free Electron Laser With a Strong Axial Magnetic Field

A small-signal theory has been derived for gain in a free electron laser in the single-particle limit, i.e. where collective effects are negligible. The model free electron laser consists of a cold relativistic electron beam in a helical magnetic wiggler, and a strong uniform axial magnetic field. Exact finite-amplitude steady-state helical orbits are included. If perturbed, these orbits oscillate about equilibrium, so that substantial gain enhancement can occur if the electromagnetic perturbations resonate with these oscillations. This gain enhancement need not be at the cost of frequency up-shift. As a result one can design amplifiers which are shorter, and require much weaker wigglers, than the corresponding device without the axial magnetic field.